A TEST OF A 2,500 K. V. A. TURBO-GENERATOR

BY

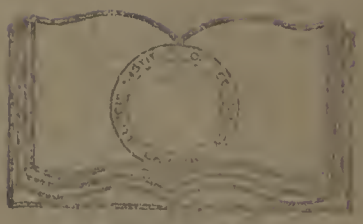
C. A. GRABENDIKE

R. O. KLENZE

ARMOUR INSTITUTE OF TECHNOLOGY

1921

537.832
G 75



Illinois Institute
of Technology
UNIVERSITY LIBRARIES

AT 577
Grabendike, C. A.
A test of a 2,500 KVA
turbo-generator

A TEST OF A 2,500 K. V. A. TURBO-GENERATOR

21203/2

A THESIS

PRESENTED BY

C. A. GRABENDIKE AND R. O. KLENZE

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE

IN

ELECTRICAL ENGINEERING

JUNE 2, 1921

APPROVED

E. H. Freeman

Professor of Electrical Engineering

Dean of Engineering Studies

Dean of Cultural Studies

ILLINOIS INSTITUTE OF TECHNOLOGY
PAUL V. GALVIN LIBRARY
35 WEST 33RD STREET
CHICAGO, IL 60616

E37.33E
S75

ACKNOWLEDGMENT.

In presenting this thesis we, the writers, wish to express our sincere appreciation, to Armour & Co., Mr. P.W. Evans, and Mr.Noble of the Motive Power department, who have been kind enough to give us the use of their apparatus, their time and their assistance in obtaining the necessary data on this test.

Inasmuch as Armour & Co. have never made a test onthis unit since its installation, we hope that the results obtained will be of value to them in determining the actual conditions under which they are operating.

29819

Digitized by the Internet Archive
in 2009 with funding from
CARLI: Consortium of Academic and Research Libraries in Illinois

http://www.archive.org/details/testof2500kvatur00grab

INDEX

PART ONE

Method of Procedure.

PART TWO

Description of the Unit.

PART THREE

The Magnetization Curve.

PART FOUR

The Voltage Regulation.

PART FIVE

The Load Run.

PART SIX

Calculations.

PART SEVEN

Data and Curves Obtained from the Test.

PART EIGHT

Conclusions.

PART ONE

METHOD OF PROCEDURE.

The test of a 2500 K.V.A. Allis-Chalmers Turbo-Generator Unit comprises the subject of this thesis, and it is the commercial testing of the unit, under operating conditions that the writers will present with complete calculations and detailed descriptions of the methods of testing, and of the units. It was decided after a general survey of existing conditions to run the test under the conditions that the unit was then operating, even though they were not such as would lead to most efficient operation.

The various instruments were first calibrated, and adjusted to read within the limits of their scales for the conditions under which they were to be used. The flow meters and the calorimeter were then tapped into the steam lines by the steam fitter and were tested out. The electrical instruments were cut in behind the switch board, between the alternator

and the high tension bus.

The primary results to be obtained are, the pounds of steam per K.W.Hour taken by the turbine and the pounds of steam per K.W.Hour taken by the auxiliaries, and, in addition, a saturation curve is to be obtained for the alternator and the per-cent voltage regulation. This requires three separate runs, and the method for each run was as follows:

RUN #1. - NO LOAD SATURATION CURVE.

The generator will be run under no load conditions, at constant speed, and the field excitation varied from zero to 60 amperes at regular intervals. The exciter voltage is to be kept constant at 98 volts. Take readings of:

Generator speed - constant, 3600 R.P.M.
Generator voltage
Field current - 0 - max. 10 Amp.intervals.
Field voltage - constant, 98 volts.

RUN #2. - VOLTAGE REGULATION.

The generator will be operated under normal full load conditions e. i. 3600 R.P.M. - 60 cycles, 2000 K.W., and 80% P.F. The value of the field current under these conditions is to be obtained.

The generator is then operated under no load conditions with the same excitation used for full load, and at the same speed. The terminal voltage is then read. The following equation gives the per cent of voltage regulation.

$$\% \text{ voltage reg.} = \frac{E_o - E_f}{E_f} \times 100$$

RUN #3. - LOAD RUN.

The generator will be operated under normal conditions as previously specified and with full field excitation of 60 amperes. The P.F. of the load is to be 80%. The load is then varied from zero to maximum (627 amp. per line) at regular intervals.

The generator voltage, and frequency are to be kept constant, also the current and voltage for

excitation. Readings are to be taken as follows:

GENERATOR:

Load Current

Load Voltage

Load Power

Exciter Voltage

Exciter Current

Generator Frequency

Generator Speed

TURBINE:

Vacuum in inches HG.

Steam Flow - Inlet

Calorimeter- Pressure and Temperature

Exhaust Steam Temperature

CONDENSER:

Water Flow - Inlet

Water Temperature - Outlet

Water Temperature - Inlet

CONDENSER PUMP

Steam Flow Inlet

LOCATION OF ELECTRICAL & STEAM INSTRUMENTS

ELECTRICAL INSTRUMENTS; The electrical instruments were grouped together on a small bench for convenience in taking simultaneous readings. Insulated wires were run from them to the rear of the switch board.

While the unit was shut down the main bus-bars were disconnected and current transformers were connected in the lines between the alternator and the bus-bars and their secondary windings short-circuited temporarily until connections were made with the ammeters. When the ammeters were connected with the transformers the short was then broken, throwing the ammeters into circuit.

It was first intended to use the potential transformers that were permanent in the connections and connect our voltmeter at the voltmeter plays on the switch board. After several attempts to do so and considerable

investigation, we found that these connections could not be made, due to a feed-back in the circuit that made the voltmeter read incorrectly. Auxiliary potential transformers were then obtained and connected in the main bus-bar circuit.

A double pole, double-throw, switch was used to throw the voltmeter from one phase to the other.

We used the direct-current ammeter, that was connected in the switch board exciter circuit, to obtain our readings for current consumption of the exciter.

The regular switch board equipment was used when starting or paralleling the unit with other units.

The steam instruments were connected at those points where correct readings could be obtained.

STEAM INSTRUMENTS: A G.E. Flow Meter was tapped in the vertical section of the steam line and a right angle globe valve tapped into the line at the same height to which was

attached a Throttling and Evaporating Calorimeter.

With this type of calorimeter the quality of the steam was calculated from the temperature and pressure readings that were taken with each set of data.

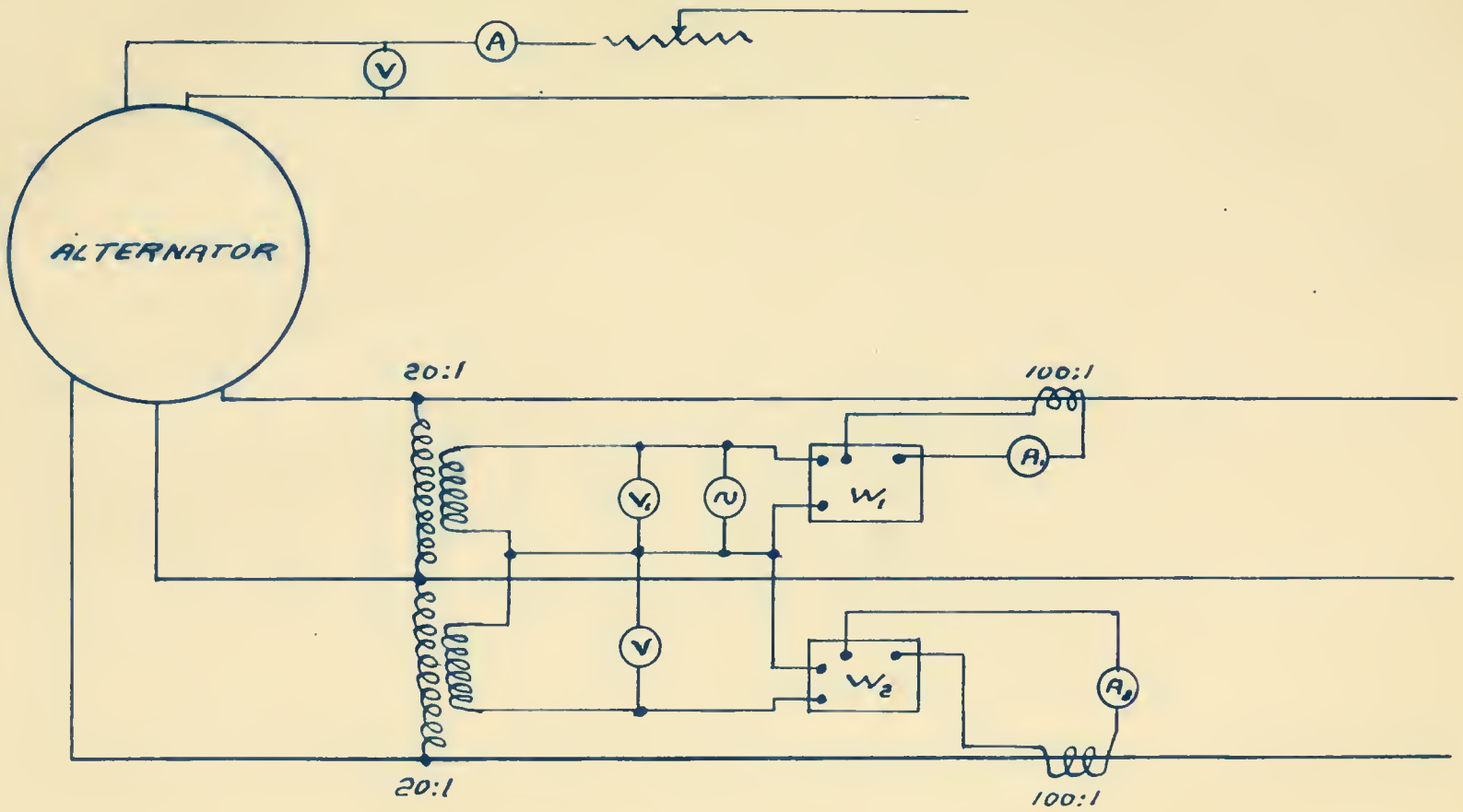
The exhaust steam nozzle of the turbine was tapped and a thermometer cup inserted. This cup was filled with mercury providing a metallic contact with the thermometer and excluding all air, which gave a correct temperature reading for the exhaust steam. A thermometer cup was also tapped into the condenser outlet pipe in the same manner, to record the temperature of the outlet water from the condenser.

A thermometer was hung in the cold water supply well to determine the temperature of the water entering the condenser.

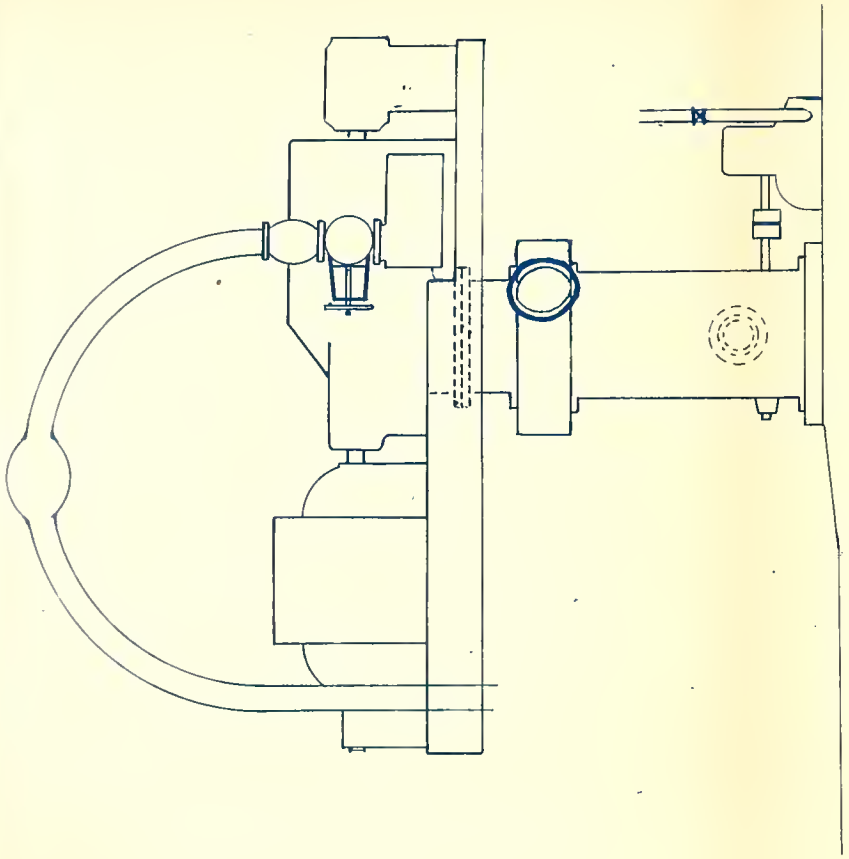
A G.E. Flow Meter is tapped in the steam line to the removal pump turbine to determine the steam consumption of the removal pump.

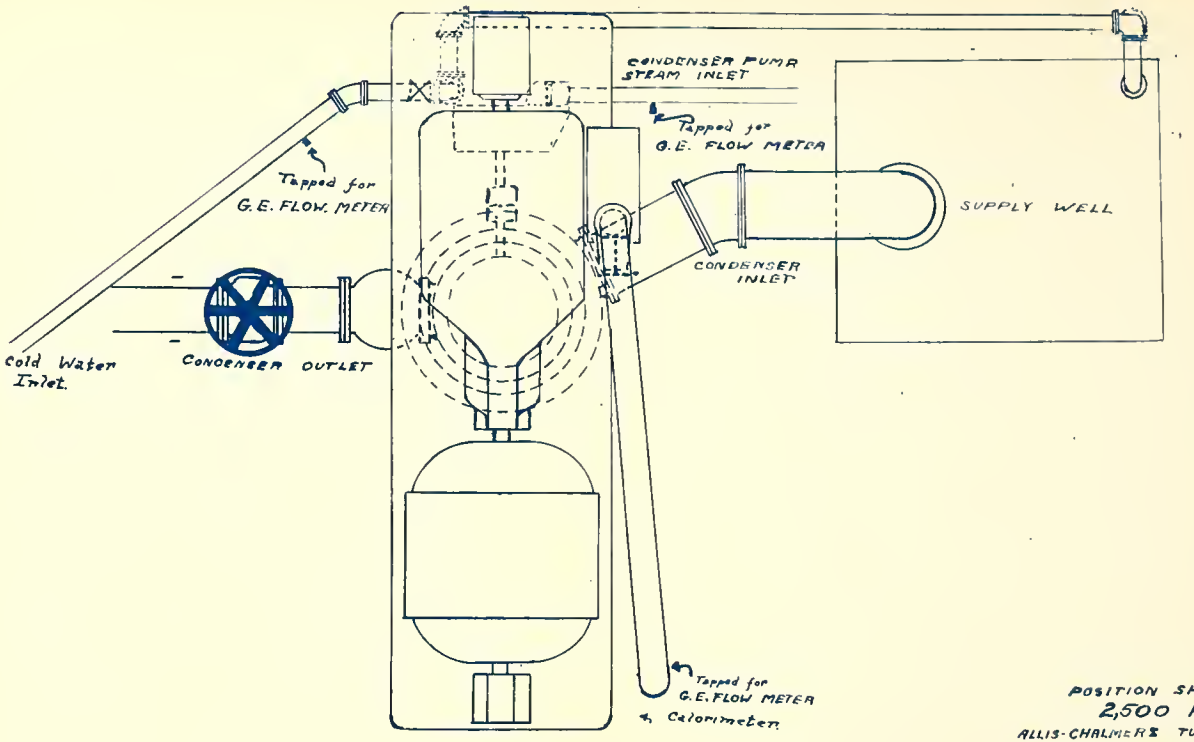
We first attempted to measure the flow of the supply water to the condenser with a G.E. Flow Meter but the velocity of the water was too great for the constants and mechanism of the instrument so it was necessary to substitute a mercury manometer and determine the flow from the difference in pressure and the constants of the nozzle.

Another mercury manometer was connected to the vacuum chamber to read the vacuum in inches of mercury at the exhaust end of the turbine. The manometer was mounted on the wall and piped to the turbine guage panel where it was tapped into the line.



ELECTRICAL CONNECTIONS FOR TEST ON 2500 K.V.A.
ALLIS-CHALMERS TURBO-GENERATOR





POSITION SKETCH
2,500 K.V.A.
ALLIS-CHALMERS TURBO-GEN.
and AUXILIARIES.

ARMOUR & CO. - POWER HOUSE.

SCALE 1 in. = 4 FT.

4-7-21. CHICAGO, ILL.

PART TWO

DESCRIPTION OF THE UNIT & AUXILIARIES.

THE UNIT: The turbo-generator set under consideration is located in the south-west corner of the generator room of the Armour & Co. Power Plant. The set consists of a High Pressure Condensing Steam Turbine and Alternator Unit.

The Steam Turbine is known as the horizontal, "Allis-Chalmers-Parsons", reaction type, connected to the generator by a flexible coupling. The rotors of the turbine, and generator are each carried in two bearings which permits them to be handled separately.

A description of the interior mechanism of the turbine cannot be given since access could not be obtained. However, an accident which occurred during the test, made it necessary to remove the bonnets and this provided an opportunity to examine the interior of the alternator.

The armature core is built up of laminated

steel held in slots in the cast iron frame. Ventilating spaces are provided thru which the air is forced. The coils are thoroughly insulated and held firmly in slots in the laminated core.

The core of the revolving field is made of steel with slots to receive the windings. The windings are of copper and held securely in the slots by wedges. The alternator is ventilated by air forced thru all parts by means of fans attached to the field structure.

The automatic governor is provided with a hand operated synchronizer which is so adjusted to allow a variation of approximately three per-cent above and below the mean speed of the unit.

The variation in speed from half to full load under ordinary operating conditions, was found to be approximately three per-cent, while a great or sudden variation would cause a momentary variation of approximately five per-cent.

The machine is also equipped with an automatic safety-stop governor which will automatically shut off the steam supply, should the unit reach a predetermined speed in excess of normal. A lever is also provided for tripping the safety-stop by hand and is conveniently located on the end of the unit.

A screw-operated throttle valve is used on the unit for steam admission and a steam strainer is encased in the pipe.

The electrical terminals from the generator lead out thru the foundation and into the basement. From there they follow the ceiling and come up behind the switch board on the balcony, thru large conduits fastened to the wall.

The foundation of the unit is large and heavy and of such construction that a minimum amount of vibration is transmitted when the unit is in operation.

THE CONDENSING EQUIPMENT.

THE CONDENSER: The condenser operated with this unit is of the Allis-Chalmers vertical, high-vacuum, jet-type of cylindrical form and it is set directly beneath the turbine, and the top of the condenser connects directly with the exhaust nozzle of the turbine. This provides a direct connection and a minimum amount of space occupied by the unit.

The shell and heads are provided with heavy machined flanges with drilled bolt holes on close centers. All joints are made with full width gaskets to insure tight joints. The exhaust steam inlet nozzle is located at the top of the condenser, while the injection, atmospheric exhaust, air suction, and water discharge nozzles are at the side. There is also a large manhole in the side of the shell that may be opened for inspection purposes. The construction on the interior of the condenser is perfected to the extent that there are no contracted water passages, no parts that require adjustment, and

nothing to get out of order.

The air connection is located at a point in the condenser where the vapors are at their greatest density, and this reduces the work of the dry vacuum pump to a minimum.

The condenser is equipped with an automatic vacuum breaker whose function is to admit air and break the vacuum, should the level of the water in the condenser rise beyond a predetermined limit. A hand control is also connected to the valve and is located between the intake throttle valve and the guage panel directly on the side of the turbine.

The condenser water, upon entrance to the shell, is distributed evenly by a slotted annular ring, fitted with auxiliary spray channels, so arranged to break the water up into fine particles. This feature along with the ample condensing chamber, permits a very thorough mixture of the water and steam.

THE WATER REMOVAL PUMP: The water removal pump is of the Allis-Chalmers, double suction, horizontal shaft, multiple runner, single stage, centrifugal type, entirely submerged in the

water in the base of the condenser.

The water enters the pump from both sides at, and directly opposite, the center of each revolving impeller, thereby providing a balanced suction. Each impeller is of the inclosed type, cast in bronze, forced on, and keyed to the shaft. The pump casing is of cast iron and of the snail shell type. The shaft is of machined, open hearth, steel, designed with a large factor of safety to insure sufficient strength. The shaft is extended on one end to receive the direct connection to removal pump turbine.

The shaft bearings are of the ring oiling type, with babbitt lined, cast iron bushings. The bearings are carried in brackets bolted to the condenser shell with heavy flanges, which are of sufficient diameter to permit the removal of the shaft and pump impellers, after the bearing brackets have been removed.

Brass water sealing rings are used in the stuffing boxes to prevent air leakage.

The base plate for the condenser, removal pump, and prime mover, is constructed of heavy cast iron, which forms a self-contained and compact unit and assures perfect alignment of the pump and prime mover.

The direct coupling between removal pump shaft and turbine shaft is of the flexible flanged face type.

REMOVAL PUMP TURBINE: The removal pump turbine is of the Allis-Chalmers, horisontal, non-condensing, impulse type. The cylinder is constructed of cast iron and divided horizontally through the center so that the upper half may be easily removed to permit inspection of the rotor.

The spindle is made of a solid steel forging onto which the blade wheel is mounted directly. The assembled rotor is balanced to assure smooth running.

The blades of the rotor are constructed of a special alloy, patented by Allis-Chalmers Co. and designed to resist erosion, corrosion, and the temperatures specified.

The turbine bearings are independent of the pump bearings and are of the ring oiling, babbitt lined type.

The speed governor is of the centrifugal type and driven by self-lubricating glaring from the turbine shaft. A separate governor is also connected which will automatically shut off the steam supply, should the unit reac.. a predetermined speed in excess of normal value. There is also a hand lever by which this governor may be tripped should it become necessary.

DRY VACUUM PUMP: The dry vacuum pump is of the Allis-Chalmers, horizontal, steam-driven, crank and fly wheel type, with the steam and vacuum cylinders attached to opposite ends of a common frame. This pump withdraws the air and non-condensable vapors from the

condenser and discharges freely into the atmosphere.

The vacuum cylinder is constructed of close-grained cast iron and thoroughly water-jacketed. It is mounted on a cast iron base plate.

The suction nozzle opens into an annular belt around the cylinder barrel midway between the ends and communicates with the interior thru suction ports which are located around the circumference of the cylinder bore. A space is left between the ports on the bottom of the cylinder to provide ample surface for carrying the piston. These ports are opened and closed by the travel of the piston giving a mechanically controlled inlet without a multiplicity of additional moving parts for this purpose.

The discharge valves are of the automatic disc type made of thin sheet steel,

hardened, and ground to their seats, and are held there by light helical springs. Each valve is mounted in a removable cage forming a valve seat and guard, the latter limiting the lift and preventing excessive shock. The assembled cage including the valve, seat, spring. and guard form a self-contained unit which is easily removed for inspection or renewal.

The suction belt drains into the cylinders thru the inlet ports and the discharge valves are placed at the lowest point in each cylinder head to insure complete discharge of all moisture and vapors, thereby making the entire cylinder self-draining. The design and construction is such that there are no pockets to allow an accumulation of water.

The piston is made of cast iron and fitted with packing rings at each end. It is also cored out making it as light as possible consistent with strength.

The vacuum piston rod is machined from open hearth steel and secured to both piston and cross head by a shoulder and lock nut.

The steam cylinder and valve are combined in one casting. The steam piston is of cast iron and box type fitted with snap rings. The piston rod is machined from open hearth steel, threaded into the cross head and secured with a lock nut and fastened to the piston by a shoulder and lock nut. The piston valve is of cast iron and carried in the valve chest in removable iron bushings. It is driven from an eccentric on the main shaft.

The governor is of the throttling type with a speed changer and safety-stop attachment, to act if the governor belt should break.

The frame and cross head guides are combined in one heavy casting with large bearing surfact on the foundation. The

cross-head is of cast iron with babbitt-faced adjustable shoes. The connecting rod is open hearth steel with solid cross head end fitted with wedge adjustable bronze boxes and marine crank end fitted with cast iron babbitt-lined boxes. The main bearings are babbitt-linged and split to provide adjustment is case of wear.

The crank shaft is of the center crank type with extenstions on both ends. Fly wheels of single casting are key seated to these extensions.

The steam cylinder is covered with non-conducting material, lagged with sheet steel. Sight feed oil cups are used for lubrication of bearing surfaces.

SWITCH BOARD AND EQUIPMENT: The switch is of the panel type and constructed of black marine slate. It is rigidly supported by iron pipe frame work. The switch board consists of the following items:-

ITEM A. 1 Swinging bracket.

" B. 1 Exciter Panel.

" C. 1 A.C. Generator Panel.

" D. 1 Blank generator panel.

" E. 1 A.C. Rotary and Transformer panel.

" F. 1 A.C. Rotary Transformer panel.

" G. 1 Swinging bracket.

" H. 1 D.C. Rotary panel.

ITEM A.

SWINGING BRACKET: mounting

1 - Synchroscope with 110 volt, 60 cycle winding and lamps, equipped with set of synchronizing plugs.

1 - 150 volt A.C. voltmeter with scale reading 2300 volts equipped with voltmeter plug.

ITEM B.

EXCITER PANEL: mounting

2 - 400 ampere D.C. ammeters.

1 - 150 volt D.C. voltmeter.

2 - Voltmeter receptacals with plugs.

2 - Rheostat hand wheel mountings.

2 - T.P.S.T. knife switches.

ITEM C.

GENERATOR PANEL: 2000 K.W. max. 80% P.F. 2300 volt, 60 cycle, 3 phase, mounting

3 - 2000 ampere A.C. ammeters.

1 - D.C. field ammeter.

1 - Synchronizing receptacle.

1 - 8 point voltmeter receptacle.

1 - Rheostat hand wheel mounting.

1 - T.P.S.T. 1500 ampere, G.E. k-12 non-automatic oil switch, hand operated, remote control, pipe frame mounting.

2 - Current transformers.

2 - Potential transformers.

ITEM D.

BLANK GENERATOR PANEL: To be used for mounting future equipment as per Item C.

ITEM E.

A.C. ROTARY AND TRANSFORMER PANEL: To control a 750 K.W. 6 phase, rotary in connection with suitable 2300 volt, step-down, 3 phase transformers for 550 volts direct current, mounting

1 - 1000 ampere A.C. Ammeter.

1 - Polyphase power factor meter.

1 - Current transformer for the above meters in the A.C. low tension rotary circuit.

1 - T.P.S.T. 800 ampere G.E. K-12 automatic oil switch hand operated, remote control, pipe frame mounting.

1 - D.P. I.T.L. overload relay for oil switch.

2 - Current Transformers.

ITEM F.

A. C. ROTARY AND TRANSFORMER PANEL: same as Item E. with the following additions considering that the rotary of this panel is to operate inverted at times and to parallel with 2300 volt bus-bars.

1 - Synchronizing receptacle.

1 - Potential transformer for connection with synchronizing receptacle and synchroscope of Item A.

ITEM G.

SWINGING BRACKET: mounting

1 - 750 volt, D.C. voltmeter, equipped with voltmeter plug.

ITEM H.

D. C. ROTARY PANEL: 750 K.W., 550 volt, 2 wire, panel, mounting

1 - Single pole, 2000 ampere, 600 volt D.C. carbon circuit breaker, with overload trip coil and low voltage release G.E. type.

1 - 2000 ampere D.C. ammeter.

1 - Voltmeter receptacle.

1 - Rheostat hand wheel mounting.

2 - S.P.S.T. 2000 main generator knife switches.

1 - Equilizer pedestal with S.P.S.T. equilizer knife switch for mounting near rotary.

ITEMS OF INTEREST.

The cold well is so located that the condenser syphons its condensing water. Water is not delivered to the condenser under pressure except when starting up or recovering its vacuum, should it be lost during operation forced injection is then used.

The maximum suction left of the condensing water including friction should not exceed the equivilant of eighteen feet head at sea level.

The horizontal distance between condenser hot and cold wells is less then twenty five feet.

Double screens are used over condenser intake pipe to prevent effectually the entrance of any foreign material which would tend to clog the water removal pump.

The condensing water should be fresh, clear and free from acids in sufficient quantities to injure cast iron parts of condenser, pumps, etc.

The condensing water should not contain more than 2% air and gas by volume.

PART THREE.

THE MAGNETIZATION CURVE.

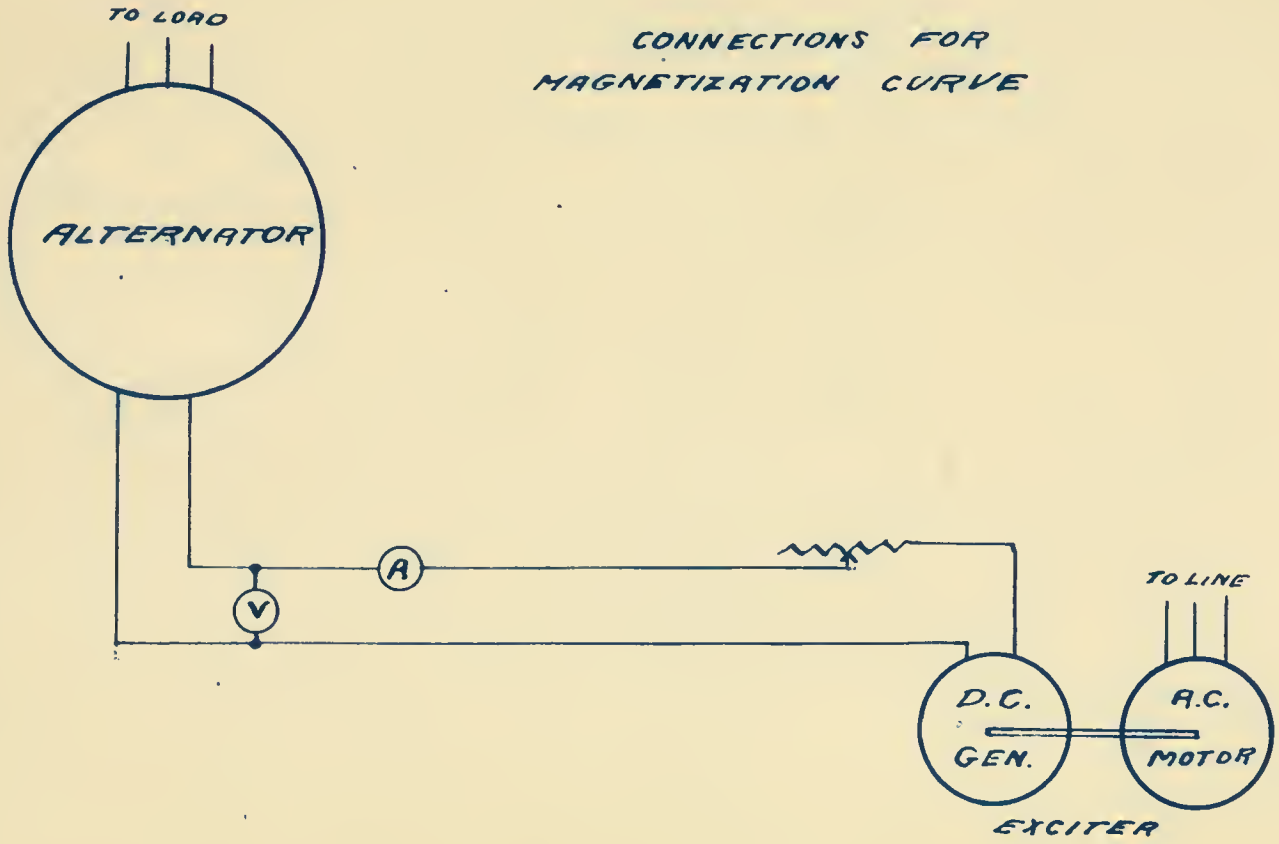
The magnetization curve, or as it is sometimes called the saturation curve, or no load characteristic is the relation between flux and terminal voltage. This is plotted with the field current as abscissa and the corresponding terminal volts as ordinates. If the magnetic circuit had constant reluctance the magnetization curve would start as a straight line through the origin, but since the permeability of the magnetic circuit falls off as the flux increases, the flux does not bear a constant ratio to the magneto-motive force. The result is that the magnetization curve drops as the field is increased. The straight portion of the curve represents a condition of affairs in which the iron of the circuit is worked at a value well below its saturation point, but as the curve begins to drop we approch the saturation point of the iron.

The magnetization curve was determined

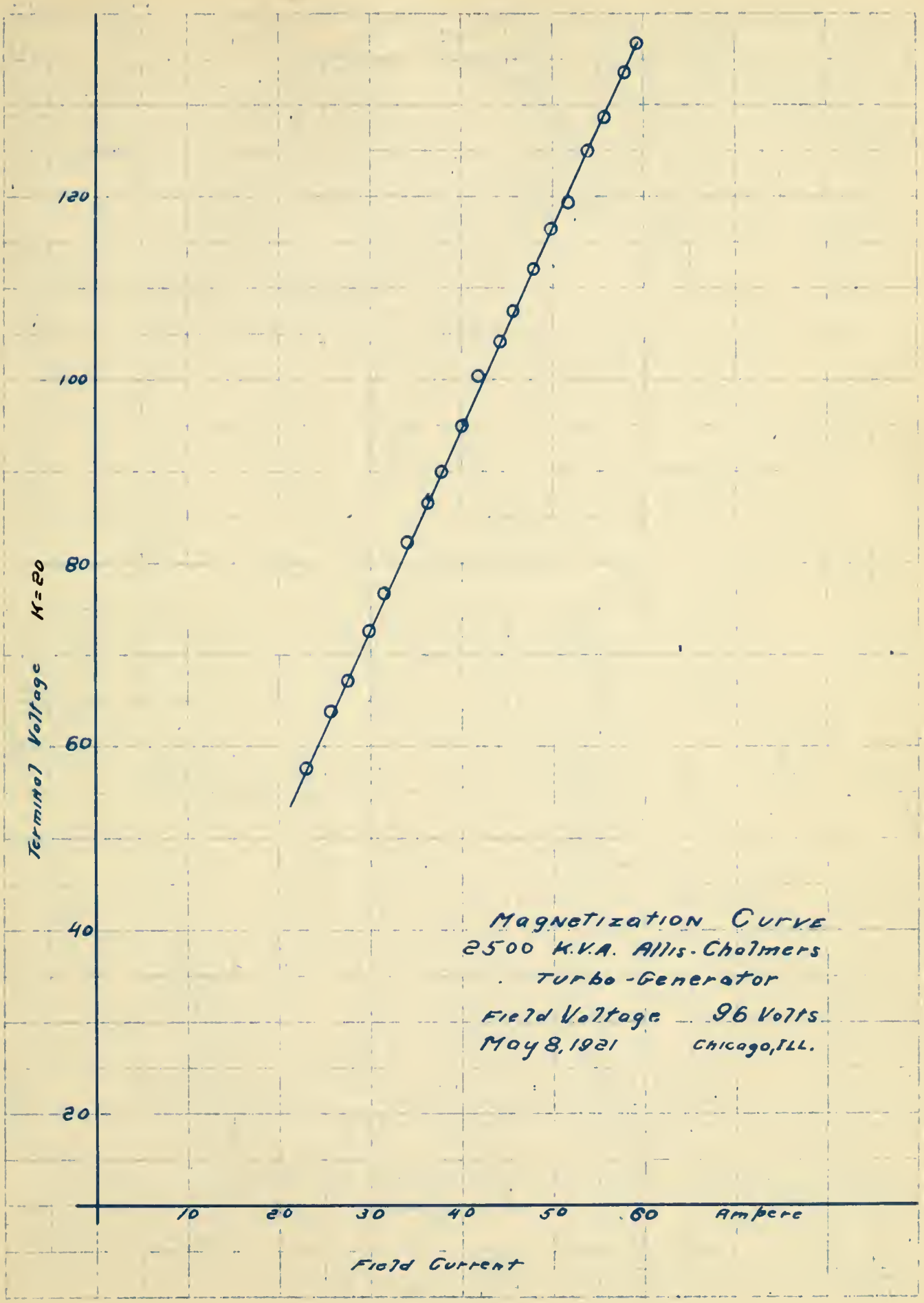
experimentally by running the generator at its rated speed and without load. The field voltage was maintained constant at its normal value and the field current varied from zero to full load value by means of resistance in the field circuit. The terminal voltage was read for each value of the field current. The data obtained are included in this section and the curve was plotted directly from these data.

The magnetization curve obtained from this generator is a straight line, as shown by the curve, which shows that we are working the iron well below the saturation point. This is very desirable, since the terminal voltage now becomes directly proportional to the excitation and this straight line relation gives a very good voltage control for the generator.

CONNECTIONS FOR
MAGNETIZATION CURVE



PART SEVEN


120
100
80
60
40
20
Terminal Voltage K=20
10
20
30
40
50
60
Ampere
Field Current
Magnetization Curve
2500 K.V.A. Allis-Chalmers
Turbo-Generator
Field Voltage 96 Volts
May 8, 1921 Chicago, ILL.

PART FOUR

VOLTAGE REGULATION.

The terminal voltage of an alternator is generally different at no load from what it is at full load, with the same value of the excitation. The difference between these two values is a measure of the regulation of the alternator for constant voltage, and this difference is called the voltage regulation. The Standardization Rules define percentage regulation as "the percentage ratio of the change in the quantity occurring between the two loads, to the value of the quantity at either one or the other load, taken as the normal value". However, since the full load value is usually considered the normal voltage, it would be used as the devisor in obtaining the percentage regulation and we may give the definition in the following manner.

The percentage voltage regulation is the difference between the full-load and no-load voltages divided by the full load voltage and multiplied by 100.

We obtained, from our test, a terminal voltage at full load of 2286 volts with an excitation of 60 amperes and 95.5 volts. The load was then removed and the voltage rose to 2740 volts with an excitation of 60 amperes and 97.5 volts. The per-cent voltage regulation of the alternator is then given by the equation

$$\% \text{ Regulation} = \frac{V_1 - V_2}{V_2} \times 100$$

V_1 = no load voltage.

V_2 = full load voltage

$$\% \text{ Regulation} = \frac{2740 - 2286}{2286} \times 100 = 19.8\%$$

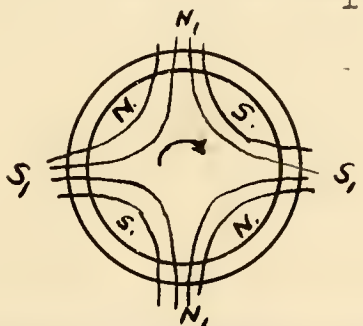
THEORY.

The underlying theory of the change in the terminal voltage of the alternator will be discussed in detail in the following paragraphs.

The decrease of terminal voltage of an alternator, with an increase in the current output, is due to several things; one being the resistance of the armature windings, another is due to self-induction and a third, the magnetizing action of the armature currents which is better understood if we divide the flux into two parts, one part being due to the field windings which produce a certain constant flux (Φ); and the other being due to the armature currents producing an additional flux (Φ_1).

The flux (Φ) produces a certain total induced electromotive force in each armature winding. A part of this total induced flux is used in balancing the armature flux (Φ_1). Another part is used to overcome armature resistance another to overcome the self-induction, while the remainder appears as the terminal voltage of the alternator. To calculate

the voltage regulation we must consider the value and phase relation of the flux (Φ_1) now in the polyphase alternator, with a balanced non-inductive load. The armature flux (Φ_1) is constant in value and space relation, for a given value of the armature currents. The electromotive forces are induced in the moving conductors as they cut this flux. When the alternator delivers current to the above load, the axis of the armature magnetizing flux (Φ_1) is at right angles to the axis of the field flux (Φ_1).



The sketch represents a four pole alternator of the revolving field type. The poles N and S are the permanent field poles, and the poles N_1 and S_1 are induced poles in the armature winding. We may consider the armature field revolving in the same direction as the rotor field, and at

unity power factor, the pole N_1 will be half way between the poles N and S.

When the alternator deliveres current to a balanced inductive load, the current lagging, the alternator field will lag thereby bringing the pole N_1 closer to the pole N and further from the pole S; thus the armature magnetizing flux (Φ_1) is shifted back through an angle θ where θ is the angle between voltage and current in the receiving circuit. If we have a balanced capacity load with the current leading the voltage by θ degrees, the armature field will be ahead of the rotor field bringing the pole N_1 closer to the pole S and further from the pole N. The axis of the flux (Φ_1) will then be shifted forward through an angle of θ degrees.

The armature flux (Φ_1) is to a certain extent opposed to the field flux (Φ) when the current lags the voltage and to a certain extent is in the direction of the field flux (Φ) when the current leads the voltage. The

armature flux (Φ_1) then seems to have no effect when the load is non-inductive, it being at right angles to the field flux (Φ).

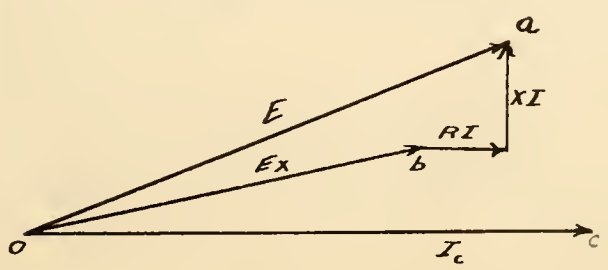
The distribution of the field flux (Φ) is not harmonic, and therefore the elctromotive forces produced by (Φ) are not harmonic. This is due to the fact that the field magnet is not uniformly distributed on the rotor but is made up of distinct poles, separated by air gaps.

The self-induction of the alternator L, is a varible and depends upon the resultant flux and the current through the windings and the expression $L\frac{di}{dt}$ is the back electromotive force induced in the armature due to its total self-induction.

It is further evident that with a non-inductive load the electromotive force induced in each armature winding by the flux (Φ_1) is 90 degrees behind the electromotive force induced by the flux (Φ), so that the portion of the total induced electromotive force (due to Θ) which is used to overcome the

electromotive force produced by ($\mathbb{D}_1$); is 90 degress ahead of the resultant induced electromotive force, or 90 degrees ahead of the current in that portion of the armature winding. The voltage and current are in phase with each other with a non-inductive load. The same relation will be found to hold true with any type of loading, that is, the portion of the total induced electromotive force which is lost in overcoming the electromotive force produced by ($\mathbb{D}$), is 90 degrees ahead of the current, in phase relation.

The lost electromotive force is also proportional to the armature current and may be expressed as XI where X is a reactance which is called the "synchroneous" reactance of the armature. The general relation between the total induced voltage (due to the flux $\mathbb{D}$) and the terminal voltage of the alternator is shown in the following sketch.



(OC) represents the current in one armature winding, (OA) represents the total induced electromotive force, and (OB) the terminal voltage. (RI) represents the electromotive force last in overcoming the armature resistance and (XI) that portion lost in overcoming the armature reaction or the armature magnetizing action.

The above discussion clearly shows why there is a change in the terminal voltage of an alternator, and more-over, for any given alternator, the percentage voltage regulation will depend upon the power factor of the load.

PART FIVE

LOAD RUN.

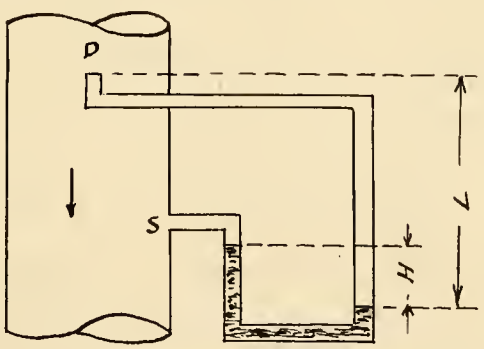
The "Load Run" of the turbo-generator unit was taken under normal operating conditions and with a load that was varied from the full load value of the alternator to a minimum value of the load. The load at the plant was in main a D.C. load, and the alternating current load was only about half the capacity of the alternator. It was necessary therefore, to convert our load to obtain complete loading for the alternator. This was accomplished by means of two rotary converters, which were installed as emergency units, to serve as a coupling between the A.C. and D.C. parts of the power plant. The two rotaries were put in operation and loaded from the D.C. side until the alternator was loaded to full capacity. The readings of all the instruments were then taken, as explained in the method of procedure for this load on the unit. The converted portion of the D.C. load was then shited back to the D.C. side by means

of the rotary converters in four steps and readings taken for each step. It now became necessary to shift the load from the alternator to get lower value, and this was accomplished by means of a reciprocating unit that served as a spare alternator. This unit was put in parallel with the alternator, and the load was shifted from the turbo-generator to the alternator, thus giving us the lower value of the load on the unit. This method of shifting the load enabled us to perform the test without interfering with the operation of the plant at a time when the load was greatest, and giving us data taken underactual operating conditions.

Two runs were taken and the data are - 3-A and 3-B, referring to these two load runs. Complete calculations were made from the first run 3-A and the results included with the observed data on the 3-A load run. The method of calculating and obtaining these results will be shown a little later. The second run 3-B was

made to check up on the steam consumption of the unit, and only such calculations were made as were required, and these results included with the observed data of the second run.

The steam flow to the unit was measured by a G.E. flow meter. This type of flow meter depends for its operation upon the displacement of a mercury column by the differential pressure action of a modified Pitot tube.



The basic principal of operation is shown by the sketch where S is the static opening, D the diameter of the opening and U an ordinary U-tube manometer partly filled with mercury. When there is no flow the suface of the two mercury columns A and B

will be at the same level and the upper portions of the tube will be filled with condensed steam. When there is a flow, the mercury will be depressed as indicated and the difference H will be a measure of the velocity of flow at the part in the pipe where the dynamic tube is placed.

In the G.E. flow meter the Pitot tube is in the form of a nozzle plug, with two sets of openings, a leading or dynamic set and a trailing set or static set. The plug is screwed into the pipe with the leading set directly facing the current and the connections made by piping to the instrument.

The movement of the mercury column is transmitted by means of a float and a system of levers to a recording pen, which leaves a trace on a circular chart which is revolved by clockwork.

This type of meter may be used to measure steam or water flow under normal conditions in pipes. The only change necessary is the proper size of plug and mechanism for the meter.

MANUFACTURERS GUARANTEE.

STEAM CONSUMPTIONS: The steam turbine unit described, when erected and properly adjusted will carry true energy steady loads as given below at 80 per cent power factor and under constant operating conditions with a consumption of dry steam not exceeding:-

26" vacuum

At One-half load or 1000 K.W. - 21.9 lbs. per K.W.hr.

At Three-quarters or 1500 K.W. - 19.9 lbs. per K.W.hr.

At Full load or 2000 K.W. - 19.95 lbs. per K.W.hr.

28" vacuum

At One-half load or 1000 K.W. - 19.00 lbs. per K.W.hr.

At three-quarters or 15000 K.W. -17.45 lbs. per K.W.hr.

At full load or 2000 K.W. - 17.0 lbs. per K.W.hr.

TURBO-GENERATOR DATA.

Rated capacity of unit at 80 per cent power factor 2000 K.W.Maximum.

Rated current per terminal 627 Amperes.

Normal Voltage 2300, Cycles 60, Phase 3.

Normal speed 3600 revolutions per minute.

Turbine to be operated condensing.

Steam pressure at turbine throttle 140 pounds by gauge.

Superheat in steam at turbine throttle none.

Vacuum at turbine exhaust nozzle 26 - 28 inches of mercury.

The maximum temperature of the generator, with 40° C. inlet air temperature, will not exceed:- at 2000 K.W., 80% Power Factor or 2500 K.V.A., 627 Amperes per terminal, 24 hour run, Stator temperature 100° C. and Rotor temperature 135° C.

Excitation voltage 125. Approximately 83 amperes excitation will be required with rated current at one hundred per cent power factor. Approximately 106 amperes excitation will be required with the same current at eighty per cent power factor.

Insulation test, a.c. for one minute: Field 1500 volts; Armature 5000 volts.

Diameter of steam inlet at turbine 7 inches.

Turbine exhaust nozzle 36inches.

Approximate overall length of unit 25 feet, 6 inches.

Approximate overall width of unit 9 feet, 4 inches.

Approximate height of hightest point of unit, above floor line 7 feet, 9 inches.

Approximate shipping weight of unit 110400 pounds.

Approximate weight of heaviest piece to be handled in erecting 32200 pounds.

Approximate weight of heaviest piece to be handled after erection 840 pounds.

Approximate amount of air required by generator per minute. (Undetermined).

PART SIX

CALCULATIONS.

The calculations of the results that were obtained will be given in detail, and in the order in which the data are tabulated, first the electrical calculations on the generator, followed by the calculations of steam consumption and turbine data, the auxilliary units, and the condenser calculations.

GENERATOR CALCULATIONS.

$$\text{K.V.A.} = K \times \frac{\text{Volts} \times \text{Amperes}}{1000}$$

$$= \frac{112.8 \times 5.35}{1000} \times 2000$$

$$= 2060 \text{ K.V.A.}$$

$$\% \text{ P.F.} = \frac{\text{KW} \times 100}{\text{K.V.A.}} = \frac{2020}{2060} \times 100$$

$$= 98\%.$$

Assume an efficiency of 94% for the generator, then the loss in B.T.U. per K.W.H. will be

$$\text{Loss} = \frac{3411}{.94} - 3411 = 219 \text{ B.T.U. per K.W.H.}$$

TURBINE CALCULATIONS.

$$\text{Lbs. steam per K.W.H.} = \frac{\text{Lbs. steam}}{\text{K.W.H.}}$$

$$= \frac{46990}{2020}$$

$$= 22.9 \text{ lbs. steam/K.W.H.}$$

The quality of steam at intake is calculated from the equation,

$$x_1 = \frac{(H + ct) - q_1}{r_1}$$

$H_1 = H + ct.$

H_1 = heat in the steam at atmospheric pressure and at a temperature that is the degree of superheat of the steam.

r_1 = latent heat of evaporation at entrance pressure.

q_1 = heat of the liquid at entrance pressure.

$P = P_1 + 14.7$

P = absolute pressure.

P_1 = gauge pressure.

$P = 130 - 14.7 = 144.7$ lbs. abs.

$$x_1 = \frac{1172.8 - 327.1}{865.5} = .96$$

Vacuum corresponding to exhaust temperature.

$V_t = V_b - V_2$

V_b = Barometer reading in inches of mercury.

V_2 = Pressure in inches of mercury corresponding to the exhaust temperature.

V_t = Vacuum in inches of mercury corresponding to exhaust temperature.

28.82 - 4.64 = 24.18 inches Hg.

The number of B.T.U. per pound of steam at the turbine entrance is calculated from the equation,

$H_1 = x_1 r_1 - q_1$

x_1 = quality of steam at entrance.

r_1 = the latent heat of evaporation at entrance pressure.

q_1 = heat of the liquid at entrance pressure.

H_1 = .97 x 865.5 - 327.2 = 1167.2 B.T.U./lb. steam.

DRY VACUUM PUMP CALCULATIONS.

The amount of steam consumed by the dry vacuum pump is estimated from the dementions and speed of the pump.

The pump is 9" x 22" x 12" running at 100 R.P.M. and with a steam pressure of 125 lbs. gauge. The steam end must develop 25 H.P. to furnish the required vacuum and will consume about 40 lbs. of steam per H.P. hour.

25 x 40 = 1000 lbs. steam used per hour by the dry vacuum pump.

EXCITER CALCULATIONS.

$$K.W. = \frac{V \times A}{1000} = \frac{61 \times 99}{1000}$$

= 6.05 K.W. required by turbine for excitation.

Assume efficiency of the exciter generator as 87%.

Assume efficiency of an A.C. motor to drive the exciter as 89%.

The combined efficiency = 87 x 89

= 77.5%

$\frac{6.05}{.775}$ = 7.8 K.W. needed for excitation.

The lbs. of steam used per hour is calculated as follows:

$$\text{Lbs. per hr.} = \frac{\text{K.W. x 3411}}{\text{B.T.U. per lbs. steam at entrance turbine}}$$

$$\frac{7.8 \times 3411}{1167} = 22.8 \text{ lbs. steam per hr.}$$

CONDENSER CALCULATIONS.

Water flow to condenser calculated from a manometer reading given in inches of mercury.

$$h = \frac{13.6}{12} \times h_1$$

$$= \frac{13.6}{12} \times 9.6 = 10.85 \text{ ft. water (head).}$$

$$V = C_V \sqrt{gh}$$

$$= .92 \sqrt{32.2 \times h} = 5.22 \sqrt{10.85}$$

$$= 17.2 \text{ ft. per sec. (velocity)}$$

$$A = \frac{Q}{V} \qquad - \qquad Q = AV$$

$$= \frac{11}{16} \times 17.2 = 3.39 \text{ cu. ft. per sec.}$$

The water flow to the condenser will then be

$3.39 \times 60 \times 62.2 = 12650$ lbs. per. min.

$3.39 \times 60 \times 7.48 = 1524$ gal. per min.

$$\frac{12650 \times 60}{2020} = 378 \text{ lbs. per K.W.Hr.}$$

The B.T.U. added to the condenser water per K.W.Hr. calculated from the condenser water temperature and flow is given by the equation.

B.T.U. = $Q \times (t_3 - t_2)$

Q = flow of water in lbs. per K.W.Hr.

t_3 = temperature of condenser water at outlet.

t_2 = temperature of condenser water at inlet.

$378 \times (114 - 72.5) = 15700$ B.T.U. added to the condenser water per K.W.Hr.

The B.T.U. per lb. of steam above the temperature of the outlet water is calculated as follows:

$H_1 - (t_3 - 32) = H_3$

$1167.2 - (114 - 32) = 1085.2$ B.T.U. per lb. of steam; above 114° F.

The steam consumption of the turbine calculated from the condenser water in B.T.U. per K.W.Hr. is given by the equation.

$$\frac{\text{Total B.T.U. per K.W.H. (calc.)}}{H_3} =$$

$\frac{19326}{1085} = 17.8$ lbs. steam per K.W.Hr.

ALTERNATOR DATA 3.-B.

RUN	WATTS 1.	WATTS 2.	AMP. 1.	AMP 2.	VOLTS	CYCLES	R.P.M.	K.W.	K.V.A.	% P.F.	
	K=2,000	K=1000	K=100	K=100	K=20						
1.	380	660	3.55	3.45	117	60	3600	1420	1415	100.5	
2.	520	K=2000 475	3.95	4.90	116			1990	1980	102	
	520	485	5.00	4.90	113.5			2010	1950	103	
	510	480	4.85	4.85	114			1980	1900	104	
3.	395	350	3.65	3.60	118			1490	1480	100.5	
	405	350	3.65	3.70	117			1510	1490	101.5	
4.	340	295	3.15	3.10	115			1270	1250	102	
	340	290	3.15	3.05	116			1260	1245	101	
	345	305	3.20	3.15	116.5			1300	1280	101.5	
5.	K=1000 540	K=1000 460	2.50	2.50	116			1000	1005	99.5	
	550	465	2.50	2.50	116			1015	1005	101	
6.	380	260	1.65	1.60	116			640	650	98.5	
	396	265	1.65	1.60	116			663	650	102	
7.	290	100	1.25	1.20	113.5			390	482	81	
	255	80	1.20	1.15	112.5			335	466	72	
	260	78	1.35	1.20	113.5			338	502	70	

TURBINE DATA

3-A

RUN	Calorimeter GAUGE PRES.	TEM. °F	QUALITY OF STEAM T1	TEM. EX. STEAM °F T4	VACUUM TO T4 IN. HG	STEAM FLOW METER READING F-S-8	LBS. STEAM PER HR.	LBS. STEAM PER K.W.H.	B.T.U. PER LB. OF STEAM		
1.	130	258	.970	131	24.18	7.1	46,990	22.9	1167		
2.	127	280	.976	142	22.64	5.6	36,500	20.3	1173		
3.	130	263	.980	133	23.83	4.7	31,350	21.6	1176		
4.	128	260	.977	131	24.18	4.6	30,100	22.8	1171		
5.	127	261	.977	135	23.66	3.8	24,780	21.8	1173		
6.	127	261	.977	133	23.83	3.8	24,780	24.2	1173		
7.	129	266	.980	133	23.93	3.8	24,900	25.0	1175		
8.	131	262	.981	131	24.18	3.5	23,200	26.8	1174		
9.	128	260	.978	131	24.18	2.4	15,700	45.0	1172		

AUXILIARY UNITS 3-A

RUN	EXCITOR D.C. Amp	EXCITOR D.C. Volts	EXCITOR OUTPUT K.W.	EXCITOR INPUT K.W.	LBS. STEAM PER HR.	CONDENSER REMOVAL PUMP FLOW METER READING	CONDENSER REMOVAL PUMP STEAM POUNDS PER HR.	CONDENSER REMOVAL PUMP STEAM LBS. PER K.W. HR.	DRY VACUUM PUMP STEAM IN LBS PER HR.	TOTAL FOR POUNDS PER HR.	STEAM AUX. LBS. PER K.W. HR.
1.	60.5	99	6.02	7.78	22.8	4	5,000	2.48	1000	6,022	2.9
2.	60	100	6.00	7.75	22.5	4	4,935	2.6	1000	5,957	3.5
3.	59	100	5.90	7.61	22.1	3.7	4,840	3.2	1000	5,662	3.9
4.	62	100	6.20	8.00	23.3	4	4,940	3.7	1000	5,963	4.5
5.	60	97	5.83	7.52	21.9	3.7	4,620	4.0	1000	5,642	5.0
6.	62	100	6.20	8.00	23.2	3.8	4,690	4.7	1000	5,713	5.6
7.	60	97	5.82	7.50	21.8	3.8	4,710	4.7	1000	5,722	5.7
8.	54	94	5.06	6.54	19.0	3.8	4,760	5.6	1000	5,779	6.7
9	52	92	4.80	6.20	18.0	3.9	4,820	13.8	1000	5,838	16.7

CONDENSER DATA 3-A

RUN	CONDENSER WATER TEM. INLET T_2	CONDENSER WATER TEM. OUTLET T_3	VACUUM TO T_3 IN. HG.	$VT_3 - VT_4$	VACUUM ON CONDENSER IN. HG.	MANOMETER WATER INLET IN. HG.	WATER FLOW GALLONS PER MIN.	WATER FLOW POUNDS PER MIN.	LBS. PER K.W. HR.	$T_3 - T_2$	
1.	72.5	114	25.92	1.74	23	9.6	1520	12,650	377	41.5	
2.	73	114	25.92	3.28	23.2	9.8	1540	12,780	326	41.0	
3.	74	108	25.38	2.45	23	9.3	1500	12,500	518	34	
4.	74	99	26.95	2.77	23.4	9.3	1500	12,500	569	25	
5.	74	101	26.64	2.98	23.2	9.3	1500	12,500	654	27	
6.	69	99	26.95	3.02	23.4	9.3	1500	12,500	735	30	
7.	73.	100	26.89	2.96	23.4	9.3	1500	12,500	750	27	
8.	75	99	26.95	2.77	23.7	9.3	1500	12,500	882	24	
9	76	89	27.45	3.27	23.8	9.3	1500	12,500	2140	13	

CALCULATIONS FROM CONDENSER WATER						
RUN	B.T.U. added per K.W.Hr. to condenser water	B.T.U. loss in gen. per K.W.Hr.	B.T.U. to S.W. per K.W.Hr.	Total B.T.U. used per K.W.Hr.	B.T.U. per lb. steam above 73	Lbs. steam to turbin per K.W.Hr.
1.	15,700	215	3411	19,326	1085	17.8
2.	17,500	215	3411	21,120	1091	19.3
3.	17,600	215	3411	21,120	1100	19.3
4.	14,200	215	3411	17,825	1104	16.3
5.	17,600	215	3411	21,220	1104	19.2
6.	22,000	215	3411	25,620	1106	23.2
7.	20,200	215	3411	23,820	1107	21.5
8.	21,000	215	3411	24,820	1107	22.4
9.	27,800	215	3411	31,420	1115	28.2

ALTERNATOR DATA 3.-B.

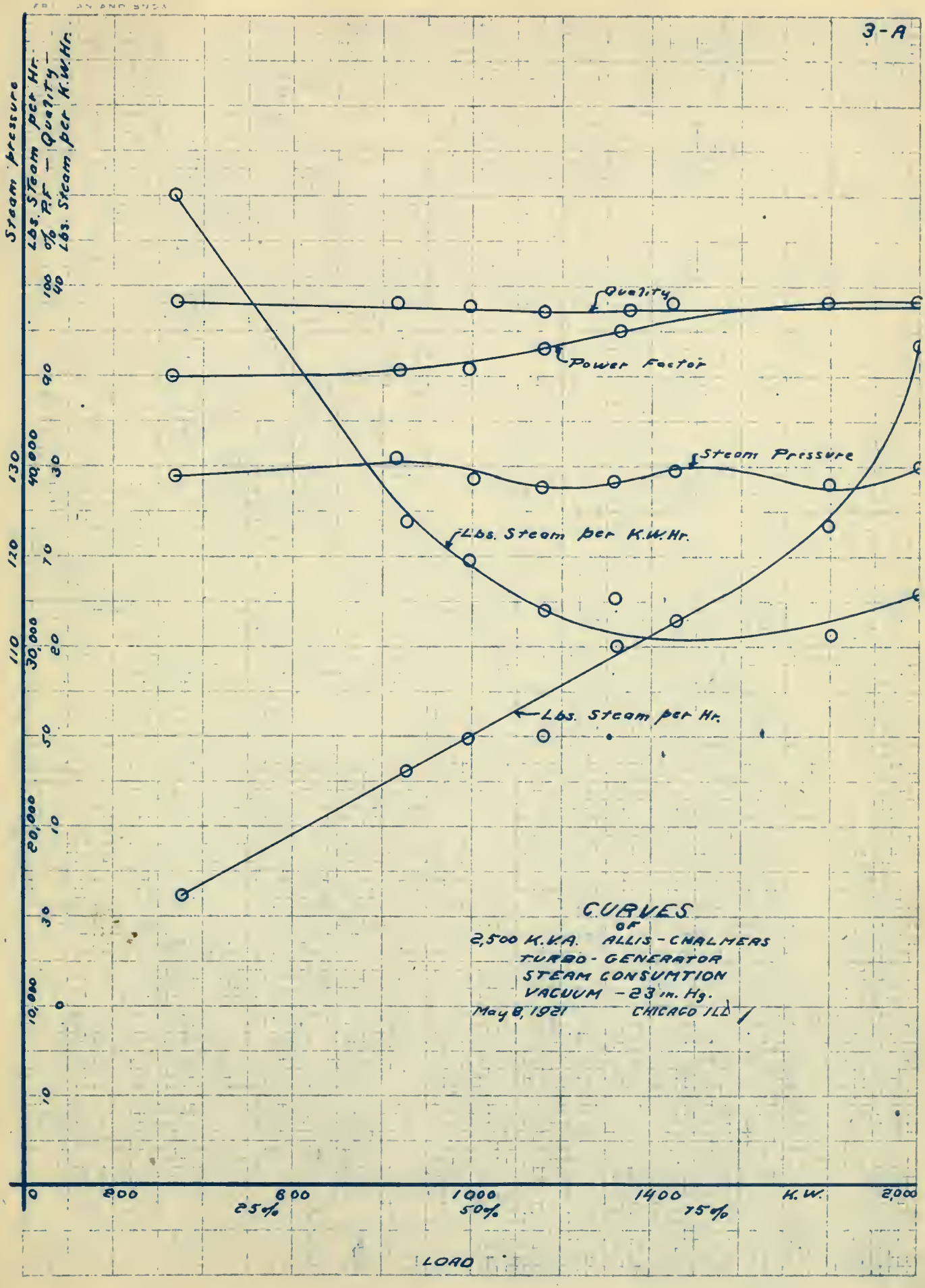
RUN	WATTS 1.	WATTS 2.	AMP. 1.	AMP 2.	VOLTS	CYCLES	R.P.M.	K.W.	K.V.A.	% P.F.	
	K=2,000	K=1000	K=100	K=100	K=20						
1.	380	660	3.55	3.45	117	60	3600	1420	1415	100.5	
2.	520	K=2000 475	3.95	4.90	116			1990	1980	102	
	520	485	5.00	4.90	113.5			2010	1950	103	
	510	480	4.85	4.85	114			1980	1900	104	
3.	395	350	3.65	3.60	118			1490	1480	100.5	
	405	350	3.65	3.70	117			1510	1490	101.5	
4.	340	295	3.15	3.10	115			1270	1250	102	
	340	290	3.15	3.05	116			1260	1245	101	
	345	305	3.20	3.15	116.5			1300	1280	101.5	
5.	K=1000 540	K=1000 460	2.50	2.50	116			1000	1005	99.5	
	550	465	2.50	2.50	116			1015	1005	101	
6.	380	260	1.65	1.60	116			640	650	98.5	
	396	265	1.65	1.60	116			663	650	102	
7.	290	100	1.25	1.20	113.5			390	482	81	
	255	80	1.20	1.15	112.5			335	466	72	
	260	78	1.35	1.20	113.5			338	502	70	

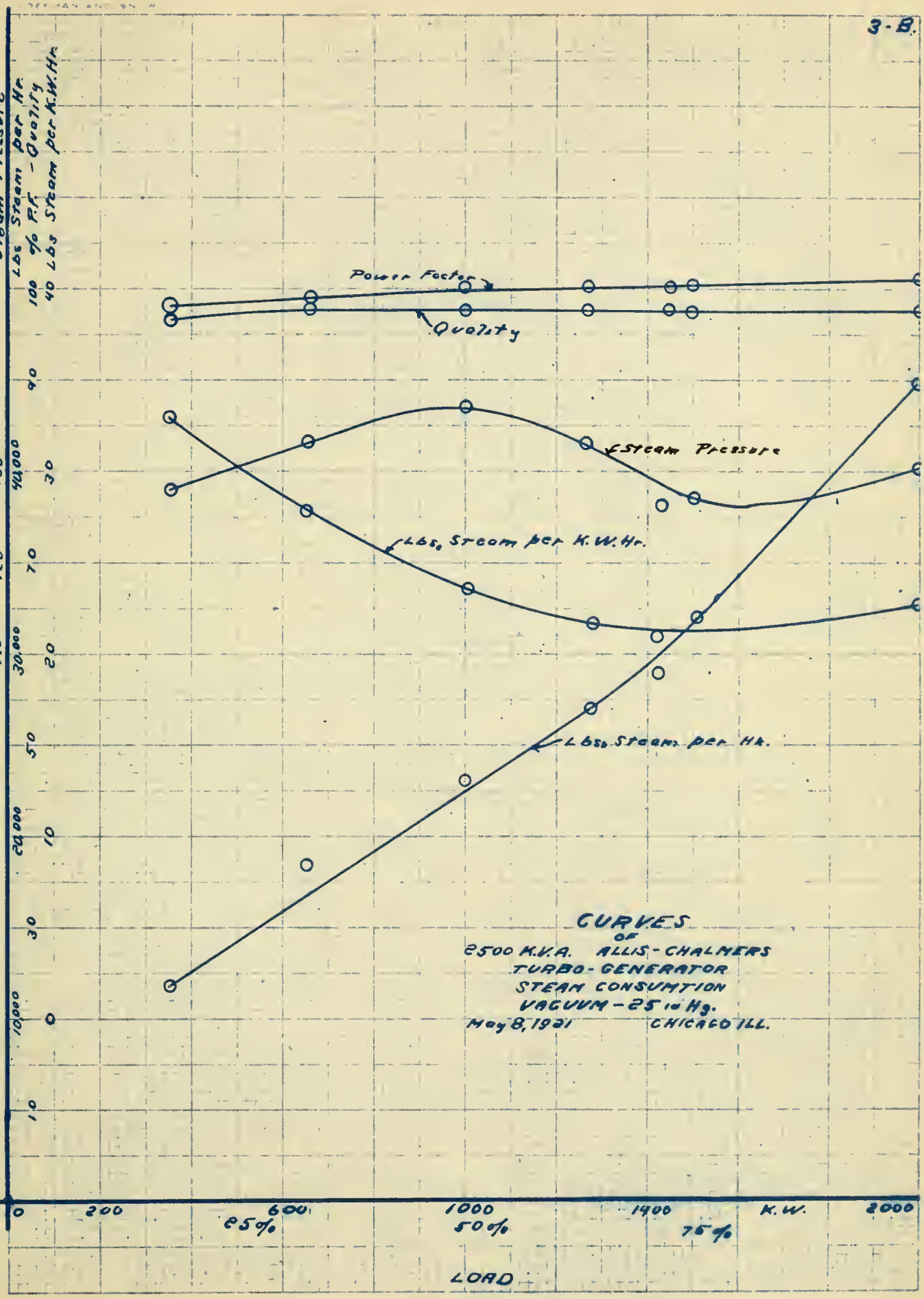
TURBINE AND REMOVAL PUMP DATA 3-B

RUN	CALORIMETER GAUGE PRES.	CALORIMETER TEM OF T_1	QUALITY OF STEAM	TEM. EL. STEAM OF T_4	STEAM F.M. TO F.S.6. TURBINE	LBS. STEAM PER HR.	LBS STEAM PER K.W.H.	REMOVAL PUMP FLOW METER F.S.6	REMOVAL PUMP STEAM LBS. PER HR.		
1.	125	255	.975	126	4.6	29,700	20.9	4.0	4,880		
2.	130	260	.976	122	6.8	44,750	22.5	4.0	4,968		
3.	127	259	.976	124	5.0	32,600	21.7	4.0	4,930		
4.	133	260	.975	126	4.1	27,440	21.6	3.7	4,650		
5.	137	259	.976	129	3.5	23,580	23.4	3.7	4,710		
6.	133	256	.975	121	2.7	17,900	27.5	3.7	4,650		
7.	128	256	.966	118	1.8	11,740	32.8	3.8	4,560		

CONDENSER AND AUXILIARY UNIT DATA 3-B.

RUN	CONDENSER WATER TEM. INLET T_2	CONDENSER WATER TEM. OUTLET T_3	VACUUM ON CONDENSER IN. HG.	MANOMETER WATER WATER INLET IN. HG.	WATER FLOW GALLONS PER MIN	WATER FLOW POUNDS PER. Hr.	EXCITER D.C. AMP.	EXCITER D.C. VOLTS	EXCITER INPUT K.W.		
1.	68	95.8	25.3	9.4	1499	12,450	58	99	5.7		
2.	68	108.7	24.2	9.4	1499	12,450	61	98	5.9		
3.	68	98.6	24.5	9.4	1499	12,450	59	99	5.8		
4.	69	93.2	25.1	8.9	1460	12,180	57	97	5.5		
5.	69	93.2	25.4	8.9	1460	12,180	55	95	5.2		
6.	68	84.2	25.8	8.9	1460	12,180	55	94	5.2		
7.	68	81.6	26.0	8.9	1460	12,180	53	91	4.8		


3-A
Steam pressure
Lbs. Steam per Hr.
% P.F. — Quality —
Lbs. Steam per K.W.Hr.
Quality
Power Factor
Steam Pressure
Lbs. Steam per K.W.Hr.
Lbs. Steam per Hr.
CURVES
OF
2,500 K.V.A. ALLIS-CHALMERS
TURBO-GENERATOR
STEAM CONSUMTION
VACUUM -23 in. Hg.
May 8, 1921 CHICAGO ILL
0
200
600
1000
1400
K.W.
2,000
25%
50%
75%
LOAD


3-B.
Steam Pressure
Lbs Steam per Hr.
100 % P.F. - Quality
40 Lbs Steam per K.W. Hr.
Power Factor
Quality
Steam Pressure
Lbs. Steam per K.W. Hr.
Lbs. Steam per Hr.
130
120
110
40,000
30,000
20,000
10,000
90
70
50
30
10
1.0
0
200
600
1000
1400
2000
K.W.
25%
50%
75%
LOAD
CURVES
OF
2500 K.V.A. ALLIS-CHALMERS
TURBO-GENERATOR
STEAM CONSUMTION
VACUUM - 25 in Hg.
May 8, 1921 CHICAGO ILL.

PART EIGHT

CONCLUSIONS.

The steam consumption curves, as drawn from our data, show that with an increase in vacuum the steam consumption will be decreased which is what might be expected. The vacuum under which this turbine is operating is rather low, and by comparing the observed vacuum with that corresponding to the exhaust temperature it becomes evident that there is a rather large air leak in the condenser.

The water flow through the condenser was varied, and it was found that the flow was twice as great as required, this being checked by the temperature of the outlet water. It was estimated that this would amount to a savings of about Seventy-Five Dollars ($75.00) a day to the company.

The steam consumption curves, being compared to the guarantee given by the manufacturer, as included in part five lead us to say that under the existing conditions

the turbo-generator unit is performing at a steam consumption per K.W. hour which is greater than might be expected from the manufacturers guarantee.

The writers respectfully submit this thesis as a test of the Allis-Chalmers Turbo-Generator Unit at Armour & Co. which we found to be performing very satisfactorily under existing conditions.

R. O. KLENZE.

C. A. GRABENDIKE.